Flexigas theme A-WPA2: Research proposal

Hanze Research – Energy / University of Groningen – ESRIG

Researching and modelling energy efficiency, sustainability and flexibility of biogas chains

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ABSTRACT

Biogas can be seen as a flexible and storable energy carrier, capable of absorbing intermittent energy production and demand. However, the sustainability and efficiency of biogas production as a flexible energy provider is not fully understood. This research will focus on simulating biogas production within decentralised energy systems. Within these system several factors need to be taken into account, including, biomass availability, energy demand, energy production from other decentralised energy sources and factors influencing the biogas production process. The main goal of this PhD. research is to design and develop a method capable of integrating biomass availability, energy demand, biogas production, in a realistic dynamic geographical model, such that conclusions can be drawn on mainly the sustainability, and additionally on the efficiency, flexibility and economy of biogas production in the near and far future (2012 to 2050), within local decentralised smart energy grids. Furthermore. This research can help determining the best use of biogas in the near and far future.

INTRODUCTION

A full transition to non-polluting renewable energies is needed to change our direction towards a worldwide energy and climatic crisis. Demand is increasing extensively and our main sources of energy are decreasing rapidly, for every barrel of conventional oil being discovered, three are being consumed (Rifkin, Edwards, 2011). Currently, fossil sources dominate the energy market, accounting for over 80% of all energy used in the world (IEA Outlook, 2009). The remainder is made up out of around 10% biomass mostly un-renewable, 6% nuclear, 2% hydroelectric and only 0.6% renewable energy sources like solar, wind, tidal, geothermic, or biogas (IEA Outlook, 2009).These sources are required in the future to replace fossil fuel dominance, as fossils grow less abundant, are more difficult to mine and become more expensive. Furthermore every unit of fossil fuel consumed creates a net greenhouse gas increase potentially adding to global warming, destabilising natural processes and endangering the Earth's carrying capacity for advanced forms of life (PCCC, 2009 and 2010), (Foster, Rahmstorf, 2011), (IPCC, 2012).

Part of the renewable transition within the Netherlands, towards the European goal of 20% renewable in the year 2020 (EU, 2012), (VROM, 2007), is focussed on decentralised renewable production and smart grid technology. Biogas produced from the (co)digestion process can play an important balancing role in future smart grid, but how sustainable is biogas production and how do you measure sustainability? Within this research *"sustainable"* biogas production is defined as: renewable, mostly un-reliant on fossil sources, not competing with agricultural land otherwise used for food production, energy efficient and not harmful to the environment.

There is a lack of integrated knowledge regarding the sustainability of biogas production. The main goal of this PhD. research is to design and develop a method capable of integrating biomass availability, energy demand, biogas production, in a realistic dynamic geographical model, such that conclusions can be drawn on mainly the sustainability, and additionally on the efficiency, flexibility and economy of biogas production in the near and far future (2012 to 2050), within local decentralised smart energy grids. Furthermore a geographic element will be added to the model, which can give insight in location of biomass sources, transport distances and location of energy demand.

Biogas, a mixture of mainly methane (50 to 60%) and carbon dioxide (39 to 49%), is extracted from biomass, which is organic material from living or recently living organisms, through a process called (co)digestion or anaerobic digestion, which is a series of processes wherein micro-organisms break down biodegradable material in the absence of oxygen to biogas (Wikipedia I, 2012). Within this research the whole process from biomass through (co)digestion to biogas is referred to as *"the biogas production chain"*. Biogas can be extracted out of biomass streams that are unsuitable for combustion, for instance wet biomass. Furthermore (co)digestion of biomass leaves a residual material after biogas is extracted called di-gestate, which can be used as fertilizer on agricultural land if certified by Dutch government, thereby reusing the nutrients in the di-gestate.

Biogas can be seen as a *"flexible energy carrier"* that can be either, stored in tanks, transformed into heat, electricity and heat or upgraded to higher quality green gas and injected in the national gas grid. Green gas is upgraded biogas to Dutch grid quality containing approximately 82% methane 14% nitrogen (Wikipedia II, 2012). Unfortunately the process of biogas production requires energy input, partially still supplied by fossils. The *"efficiency"* of the whole system can be determined by looking on the energy invested in the process and the energy returned in the shape of biogas and or di-gestate, which is often called Energy Returned On Energy Invested or *"EROEI"* for short.

The reasonably steady production of biogas throughout the year and its flexibility, make biogas very capable in balancing other more irregular decentralised renewable resources like wind and solar PV, potentially giving it a pivotal role in the future smart grid. Within a local *"smart grid"* balance between energy production and demand is pursued through the use of communication, storage of energy and controlling demand by turning appliances on and off on demand or even by influencing consumer behaviour.

PROBLEM DEFINITION

Biogas can play important balancing role in future local decentralised smart grids, but integrated knowledge is needed, which can possibly give insight on the sustainability of biogas production. To date focus has been mainly on individual parts of the biogas production chain, which include; biomass availability (Batzias et al., 2005), (Spijker et al., 2007), (Elbersen et al., 2011), (Wiskerke, 2011), (CBS, Statline, 2012), energy demand (Faber et al, 2009), (Nieuwenhout et al, 2009), (Senter Novem, 2009), biogas production (Zwart et al, 2006 and 2011), (Kool et al, 2005), and the environmental impact of biomass and biogas production (Berglund et al., 2008), (van der Hilst et al., 2012).

A start has been made on the integration of research mainly focussed on economics (T. Weidenaar et al., 2011), (Jan Bekkering et al, 2010), (van der Hilst et al., 2010), but overall, the individual parts of the biogas production chain have never been brought together in an attempt to create integrated knowledge or *"Meta knowledge"* on sustainability and additionally on the efficiency, flexibility and economy. Within this context it is also important to integrate the geographical location of biomass sources for biogas production and that of energy demand, introducing the need for *"geographical knowledge".* Integrated insight or Meta knowledge on local biogas production can help determine what is actually achievable in quantity, in quality but more importantly sustainably within future local decentralised smart grids.

APPROACH

This research will focus on three main pillars of interest representing the complete biogas system, namely; biomass availability, energy demand and the biogas production chain (see figure 1). The pillars will contain current knowledge expanded with lacking information and future prospective.

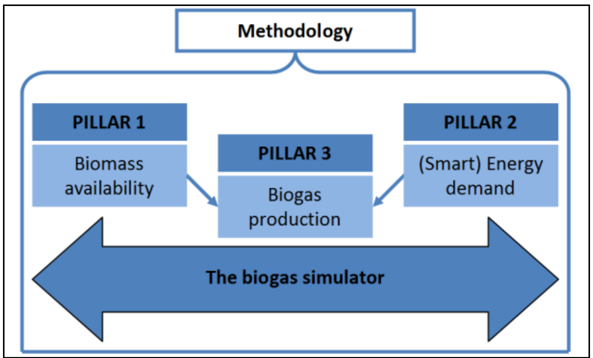

Figure 1: The tree main pillars of this research

All three pillars will be integrated within a realistic dynamic geographic model called *"the biogas simulator",* which can give an integrated insight on the sustainability of decentralised biogas production chains. The subjects and pillars will form the chapters of the PhD. thesis, together with results regarding sustainability and efficiency of biogas production originating from the biogas simulator.

Methodology

The biogas simulator will include the dynamics of decentralised energy production and demand together with the dynamics of biogas production. To integrate all properties, static and dynamic, a new method is developed specifically focussed on sustainability and efficiency of the biogas production chain. The method will be explained more extensively in the methodology chapter.

Pillar 1, biomass availability: Biogas production is dependent on current and future availability of biomass, which is not readily available at any conceivable location, quality or at any required quantity. Biomass can be specially cultivated directly competing with food production and consuming fossil energy in the process. The second option is through the use of by-products, which is environmentally preferable, but they often lack the quality. There are several factors that can influence biomass availability for instance, quality and value, biogas potential, other uses for the biomass, geographical origin, and finally future technological advancement.

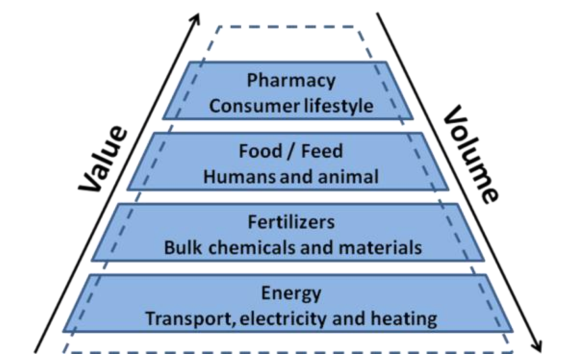

Figure 2: Value chain of biomass
Source: WTC, 2011

Overall the value of biomass is mainly determined by the quality and purity of the product, positioning it in an economic market value chain (see figure 2). Energy production occupies the lowest position in this value chain, meaning that (without subsidisation) only low value and low quality biomass is affordable for the production of biogas. Finally technological advancement within the newly developing Biobased Economy (van der Meulen et al., 2011), capable of upgrading low value biomass to higher quality components, can further compromise biomass availability for biogas production in the coming future.

Within this pillar first, the current availability and geographical location of biomass for biogas production will be determined within the Netherlands, focussing on by-products. Second, the future availability of biomass for biogas production will be researched, taking into account future technologies and developments like the Biobased economy.

Pillar 2, (smart) energy demand: The demand for energy on a local scale is determined by the consumer. When acting together in villages or districts consumers form reasonably predictable energy consumption patterns for gas and electricity. These patterns have daily recurring properties with variation depending on mostly the weather, the days of the week and occasionally special events. There are also seasonal fluctuations seen on a yearly basis, depending on the availability of natural light and the outside temperature (Faber et al., 2009), (Senter Novem, 2007).

These demand patterns can be influenced with smart grid technology by turning on and off demand at the right moment, creating buffers in appliances or influencing behaviour to consume less at particular times. Smart grid technology can be used to alter demand patterns, in an attempt to match energy production with energy demand. Within this pillar first, the current local energy demand patterns will be researched including geographical location of the demand. Second, future local energy demand patterns and their degree of flexibility, when using smart grid technology will be researched.

Pillar 3, biogas production: The biogas production chain is the link between biomass availability (pillar 1) and energy demand (pillar 2), wherein biomass is transformed and processed into biogas and di-gestate. Throughout this process additional energy inputs are required besides the main input of biomass, which are mostly still supplied by fossil sources (Zwart et al, 2011), hidden away in cultivation, transport, biogas production, upgrading and transport.

For biogas to be sustainable, additional energy consumption must be kept to a minimal and should not exceed energy output in the shape of the biogas, when doing so the biogas production chain will effectively turn in an energy storage system instead of a net energy producer. Besides biogas, Digestate can also be seen as a product, which can be separated in individual components and upgraded to fertilizers, creating environmental benefit by integrating biogas production in a natural cycle where biomass waste streams are reused.

Within this pillar first, all the energy and material flows will be mapped in an input / output analysis to determine the Energy Returned On Energy Invested (EROEI), second, life cycle analysis will be used to determine the environmental impact, or footprint on the Earth through emissions and pollution, also taking into account the reuse of di-gestate and the contained nutrients within.

The biogas simulator: Biogas can play an important role in the future local smart energy systems, it contains certain qualities that other renewable energy resources lack. Integrated insight or Meta knowledge (see figure 3) on local biogas production can help determine what is actually achievable in quantity, in quality but more importantly sustainably.

To create meta knowledge, first, the three pillars will be integrated in a realistic dynamic geographical model called *"the biogas simulator"*, which will be designed in such a way that conclusions can be drawn on mainly the sustainability, and additionally on the efficiency, flexibility and economy of biogas production in the near and far future (2012 to 2050), within local decentralised smart energy grids. Second, a geographic element will be added, which can give insight in location of biomass sources, transport distances and location of energy demand. Finally the theoretical background of the biogas simulator will be covered with a comprehensible geographical interface (comparable to the functionality of Google maps) that can inform scientist, economists, investors and planners on where to place what kind and size of biogas systems with economic and environmental perspective in mind, filling the gap between science and practice.

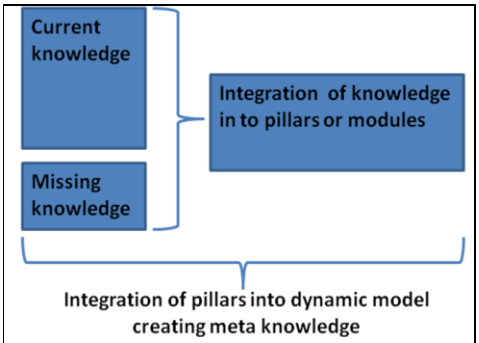

Figure 3: Applied science

RESEARCH AIMS

Project vision: The Flexigas project is working towards economic and sustainable integration of biogas into the future national and decentralised energy system, also called the smart grid (Flexigas, 2012).

Project mission: Theme A WPA2 within Flexigas is focussed on the environmental impact of the biogas production chain. The aim of this research is to create a better understanding on the influence of environmental issues on business economic models. The possibilities for translating environmental factors in the model will be investigated. This activity aims to investigate the possibilities for application of biogas. The 'optimal' application depends on many factors and scenarios. In order to develop a sustainable, continuous development of sustainable gas chains it is important to investigate several roadmaps (Flexigas 2010 PhD. descriptions).

Project goal: The main goal of this PhD. research is to design and develop a method capable of integrating biomass availability, energy demand, biogas production, in a realistic dynamic geographical model, such that conclusions can be drawn on mainly the sustainability, and additionally on the efficiency, flexibility and economy of biogas production in the near and far future (2012 to 2050), within local decentralised smart energy grids. Furthermore a geographic element will be added, which can give insight in location of biomass sources, transport distances and location of energy demand.

MAIN RESEARCH QUESTION

How to design and develop a method capable of integrating local biomass availability, energy demand and biogas production in a realistic dynamic geographical model? Such that conclusions can be drawn on mainly the sustainability, and additionally on the efficiency, flexibility and economy of biogas production in the near and far future (2012 to 2050), within local decentralized smart energy grids.

SUB QUESTIONS

The main question is divided into sub-questions, which go into more detail. The sub-questions are divided over the main pillars of the research.

The methodology behind the biogas simulator

- How to integrate a local biogas production chain into a dynamic geographic realistic model?

Pillar 1: Biomass availability

- What is the current availability of biomass usable for biogas production within the Netherlands, including energy crops, by-products and waste flows?
- What is the future availability of biomass within the Biobased economy?

Pillar 2: Energy demand

- What is the current demand for electricity, natural gas and heat in different local areas within the Netherlands?
- What is the future flexibility in energy demand, when using smart grid technology?

Pillar 3: Biogas production chain

- What is the energy returned on energy invested of an average local biogas production chain?
- What is the environmental impact of an average local biogas production chain?

Dynamic modelling: Roadmaps

- What is the most sustainable placement of a biogas production chain when incorporating local biomass availability, di-gestate demand and energy demand?
- How can biogas and smart grid contribute to matching demand and production in a local decentralised energy system?

BOUNDARIES

The boundary will be divided in two levels. Firstly, for overall knowledge regarding biomass and energy demand the main boundary will follow the boarder of the Netherlands, with the exception of bio fuel import and waste/by-product export (macro level). When modelling biogas chains a more local scale is chosen, which will drop to province (meso level) or village (micro) level, within the northern three provinces of the Netherlands. The timeframe will be set between the year 2012 and 2050, within which a lot of goals are stated by the European Union regarding sustainability (EU, 2012).

PROJECT SCOPES AND LEVELS

The project itself will know different levels based on the levels used in governmental system of spatial planning that range from macro to micro scale, including:

- Country, macro level
- North Holland*, macro level
- Province, macro / meso level
- Local government, meso level
- Village, meso / micro level
- Single unit, micro level (single house/building)

** The northern three provinces in the Netherlands are called North Holland; this scale will be used for a scenario on fuel availability and energy demand.*

METHODS

The combination of methods and tools will help to create a clear route, planning, and a structured way of working towards the final goals of the project. The following main methods will be used during the research.

Literature study: To get familiar with the subject and all the surrounding fields a literature study is the ideal starting point. The needed base of information for the research proposal and the planning will be gathered during this phase. Literature study will also return in the research of the pillars, modules and sub-modules.

Field experience: Specialists will be approached to extract additional information and knowledge. The specialists can vary from farmers, owners of biogas installations to researchers. Other players in the biogas sector can also be approached for more information.

Modular approach: The biogas production chain will be divided into modules, which are based on main steps in the biogas production chain (see figure 4 bold capital lettering). The main modules will be divided further into sub-modules to make the planning and structure more manageable (see figure 4 normal lettering). The sub-modules will be researched as individually components. Additionally, sub-modules can be outsourced to specialists or students. The modular structure will be the backbone of this research and will help keep it understandable, manageable and transparent. Most other methods will work within this modular principle.

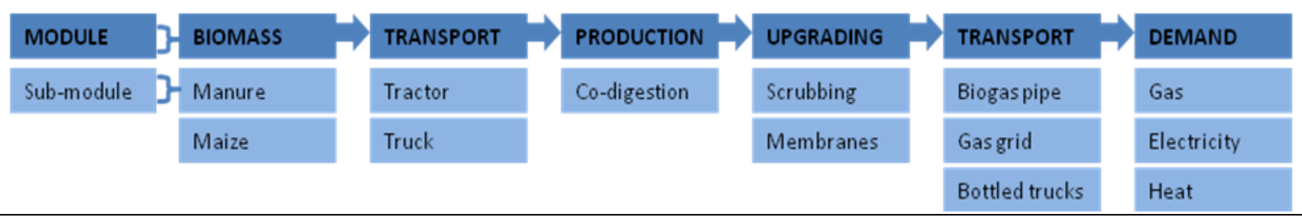

Figure 4: the main and sub-modules used in this research project

Material and energy input output analysis method: To get a good picture on the additional energy use and material flows within the biogas production chain the input output analysis method is used. First, flows of energy and material in and out of every sub-module will be analysed and researched. Second, these flows will be subjected to LCA analysis to determine their impact on the environment. Finally, the research will be integrated, resulting in a sub-module where all the flows of energy and material going in and out are defined, along with their environmental impacts (see figure 5).

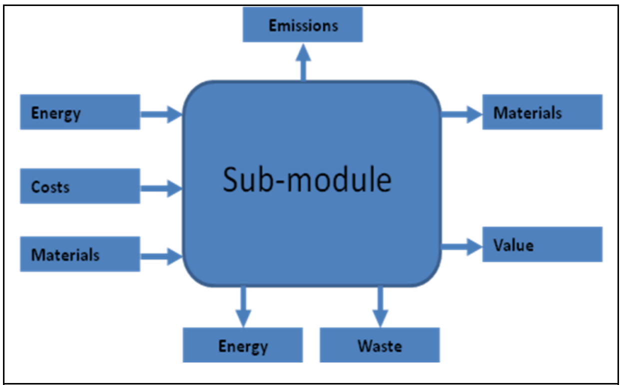

Figure 5: The black box methodology

The flows in and out of sub-module will be defined (where needed) in three values, the minimum, set point and maximum value possible. These values will be used as variable parameters within the biogas simulator. The modular approach, together with the input output analysis is a transparent method for dynamic modelling, with the added advantage of expandability with a theoretically unlimited amount of new sub-modules.

LCA method: The environmental impact of every sub-module and subsequent flows within the main biogas chain (see figure 4) will be analysed with the Life Cycle Analysis tool, SimaPro (Pre 2012). Life cycle analysis looks to the complete lifetime of the components, material flows or energy sources, incorporating the production phase, use phase and finally end of life. SimaPro is fully capable of calculating the total energy consumption, emissions and environmental impact, through the use of a proven database of life cycle analyses.

The sub-modules in the dynamic model: The sub-module will be programmed into the modelling language Modelica (Modelica 2012), as individual components. This open source programming language is comparable with Matlab and can be used for complex linear and non-linear mathematical calculations or simulations. The sub-modules will also be modelled in excel for validation and back-up of the contained data. Modelica is used as main programming language for the biogas simulator within the Flexigas project (Flexigas 2010) and represents the core of the biogas simulator.

The biogas simulator: The biogas simulator will model an entire biogas production chain which includes the biomass source, biogas production, storage, energy conversion and finally demand of the consumer. The model will start off with a fixed biogas chain running on maize and manure (see figure 4), over time the biogas chain can be expanded with more sub-modules when needed. The build-up of biogas simulator will be modular.

The core of the model will be based on the sub-modules programmed in Modelica (Modelica 2012). The sub-modules can be linked together in the biogas simulator to form a biogas production chain. Time depended variables will be integrated in the simulator through the use of yearly relative patterns with single data points per hour. These patterns make it possible to integrate fluctuating availability of biomass, fluctuating demand for energy and fluctuations in the biogas production chain. Finally, the biogas simulator will be covered with a comprehensible interface that can be used by scientists, economists or planners. The programming of the model will be performed in cooperation with TNO, as part of the Flexigas project (Flexigas 2010).

PLANNING

Time planning: For this research an overview planning is created with all main stakeholders, phases and subjects included (see figure 6). The main planning is as follows:

1. First year: drafting final research proposal; first draft of article one.
2. Second year: finalisation first article; preparation and submission second article, lectures*.
3. Third year: preparation and submission third and fourth article, lectures*.
4. Fourth year: Preparation and submission fifth article; writing introduction and conclusion thesis, lectures*.

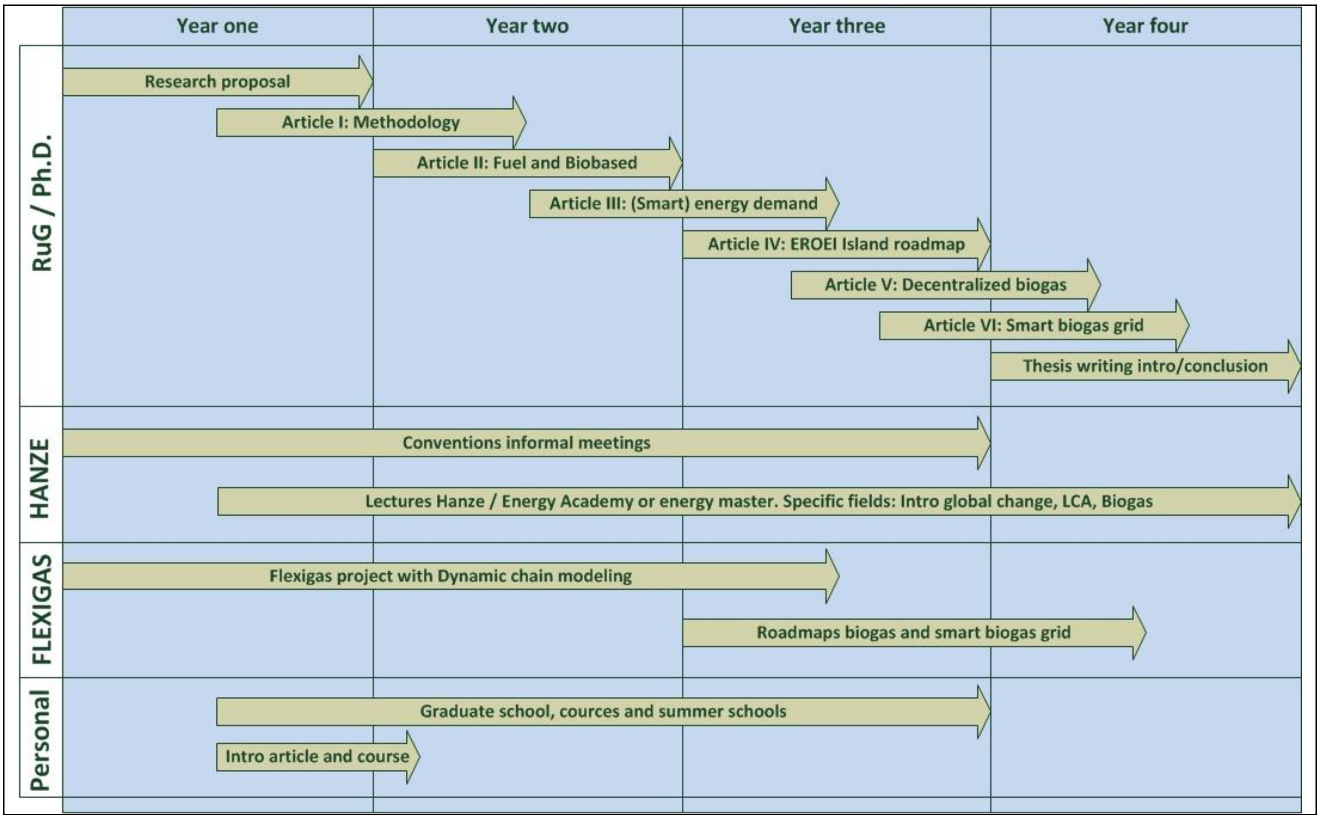

Figure 6: Draft time planning for research period

* *Within the planning, time for lectures around 20% and time for conferences and colloquium (+/- 5%) should also be incorporated.*

* *The graduate school will also demand around 10% of the available time for following and attending courses or attending conferences*

MAIN CONTENT REPORT

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3 Biomass availability incorporating the Biobased economy (article)
4 Smart regional energy demand, the flexibility of demand on regional scale (article)
5 The energy returned on invested, biogas island scenario (article)
6 Ideal placement of biogas chains, roadmaps (article)
7 Integrating biogas in a smart grid (article)
8 Conclusion
9 Recommendations
10 Discussion

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